

# Susceptibility Measurements Near the $^3\text{He}$ Liquid-Gas Critical Point

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## Abstract

An electrostriction method was used to determine the susceptibility along the critical isochore near the liquid-gas critical point of  $^3\text{He}$ . Measurements were fit to  $\chi_T^* = \Gamma^+ t^{-\gamma}(1 + \Gamma_1^+ t^\Delta)$ . Best fit parameters for the asymptotic amplitude  $\Gamma^+$  and the first correction-to-scaling amplitude  $\Gamma_1^+$  are presented.

*Keywords:* Critical Phenomena; Susceptibility

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## 1. Introduction

A microgravity experiment, called MISTE (Microgravity Scaling Theory Experiment), is being developed to test scaling predictions near the liquid-vapor critical point of  $^3\text{He}$ . One of the objectives of this experiment is to accurately measure the susceptibility along the critical isochore in the single-phase region. The susceptibility is defined as  $\chi_T \equiv \rho(\partial\rho/\partial P)_T$  with  $\rho$  being the fluid density and  $P$  being the thermodynamic pressure. The conventional technique for determining the susceptibility uses  $P$ ,  $\rho$  measurements along an isotherm [1] and is only appropriate outside the gravity affected region. Even in a microgravity environment, an accuracy of 1% in  $\chi_T$  along the critical isochore ( $\rho = \rho_c$ ) at  $t \equiv T/T_c - 1 = 1 \times 10^{-6}$  would require a pressure sensor with a resolution

of  $\delta P/P \approx 10^{-10}$ . This resolution can not easily be obtained using conventional pressure sensors.

In 1962, Hakim and Higham [2] experimentally determined that a pressure increase in a dielectric fluid could be induced by an electric field gradient. This electrostriction effect was recently validated by Zimmerli *et al.* [3] in a microgravity experiment near the critical point of  $\text{SF}_6$ . The present paper discusses our recent application of this electrostriction effect to measure the susceptibility near the  $^3\text{He}$  liquid-gas critical point.

## 2. Experiment and Results

The measurements were performed using a parallel-plate capacitor with a 0.0061 cm gap that was placed in the middle of a  $^3\text{He}$  sample cell 0.05 cm high by 11.2 cm in diameter [4]. By applying a constant bias voltage across the capacitor, a uniform electric field,  $E$ , is generated in the capacitor gap. In the limit of  $E \rightarrow 0$ , the susceptibility within the capacitor gap is given by

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This work was supported by NASA

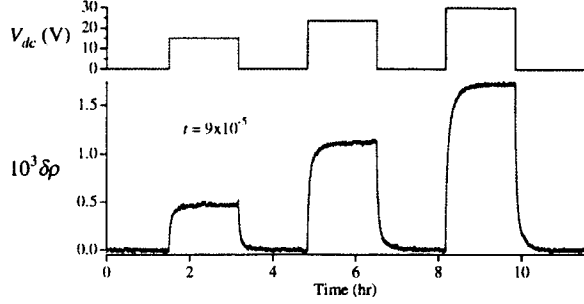


Fig. 1. Measured density change for a change in DC bias versus time. Cell temperature was controlled within 10 nK.

$$\chi_T = \frac{6\rho\delta\rho}{\epsilon_0(\epsilon - 1)(\epsilon + 2)E^2}. \quad (1)$$

Here  $\epsilon_0$  is the permittivity of free space and  $\epsilon$  is the dielectric constant of the fluid, which is related to fluid density via the Clausius-Mossotti equation. The susceptibility can thus be determined by measuring the density change upon an application of a known electric field.

Figure 1 shows measurements of the electrostriction effect at a reduced temperature  $t = 9 \times 10^{-5}$  along the critical isochore. For each change in voltage there is a corresponding change in density. The susceptibility at each measured temperature was obtained by extrapolating the data to zero field. In Fig. 2, the reduced susceptibility  $\chi_T^* = (P_c/\rho_c^2)\chi_T$  for two electrostriction runs and two  $P, \rho$  isotherm measurements in the present cell are compared to previous studies [1] [5]. The present measurements are seen to be consistent with previous work.

The susceptibility along the critical isochore in the single-phase region is expected to behave as

$$\chi_T^* = \Gamma^+ t^{-\gamma} (1 + \Gamma_1^+ t^\Delta + \dots). \quad (2)$$

The measured susceptibility data (solid circles) in Fig. 2 were fit to Eq. (2) by fixing the critical exponents to their theoretical values  $\gamma = 1.239$  and  $\Delta = 0.50$ . The critical temperature,  $T_c$  and fluid-dependent critical amplitudes  $\Gamma^+$  and  $\Gamma_1^+$  were then determined. The gravity affected data close to the transition and the less accurate electrostriction data affected by higher order correction-to-scaling terms farther away were omitted from the fit. The fit was performed over the limited reduced

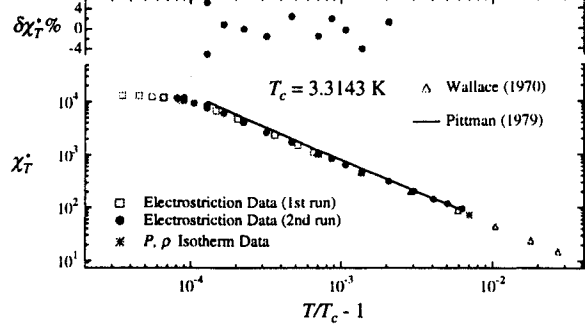


Fig. 2. Measured susceptibility versus reduced temperature along the critical isochore.

temperature range  $1.2 \times 10^{-4} < t < 2 \times 10^{-3}$ . The deviations from the fit, which are random, are shown in the upper graph in Fig. 2. The best fit values were  $T_c = 3.31429$ ,  $\Gamma^+ = 0.108$ , and  $\Gamma_1^+ = 7.24$ . There is a large correlation in the fit between  $\Gamma^+$  and  $\Gamma_1^+$ . These values are consistent with the results of Pittman and Meyer [5]. The correction-to-scaling amplitude  $\Gamma_1^+$  is large compared to room temperature fluids. This large  $\Gamma_1^+$  value for the  $^3\text{He}$  critical point may be associated with quantum effects.

There is a need to perform measurements closer to the transition to unambiguously determine the value of  $\Gamma^+$ . This is one of the objectives of the proposed microgravity flight experiment. Future ground-based experiments are planned that will combine electrostriction measurements close to the transition with  $P, \rho$  measurements farther away. This wider range of data should permit a more accurate determination of the critical amplitude  $\Gamma_1^+$ .

## References

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